Robust Epsilon Visibility

Florent Duguet and George Drettakis
REVES/INRIA, Sophia-Antipolis, France
http://www-sop.inria.fr/reves

Overview

- Introduction
- Previous Work
- Generalized Visibility Events
- Enumeration and Validation
- Robust Blocker Predicates
- Implementation and Results
- Conclusion

Introduction

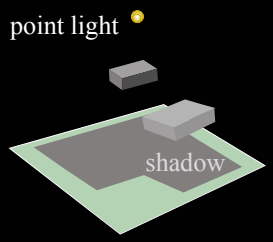
- Analytic visibility algorithms
  - continuous & precise solution, but not robust

[Durand et al. 99]

Analytic Visibility is Not Robust

- Geometric complexity and degeneracies
  - touching objects
  - coplanar edges (e.g., chairs in a concert hall)
  - aligned vertices
  - floating point arithmetic can't handle small features: geometric algorithms fail

Introduction: Shadow Boundaries



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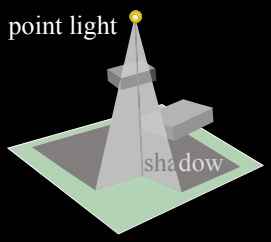

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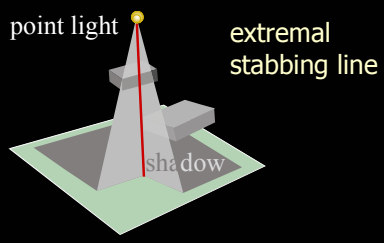

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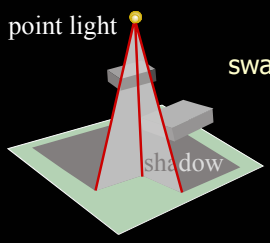
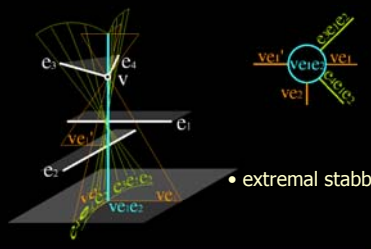


Introduction: Visibility Skeleton

- Visibility Skeleton [Durand et al. '97]



- extremal stabbing line ve_1e_2

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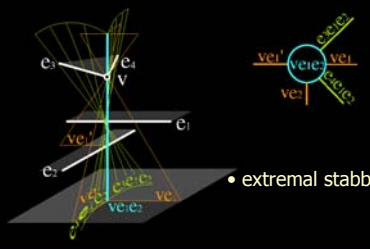

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Introduction: Visibility Skeleton

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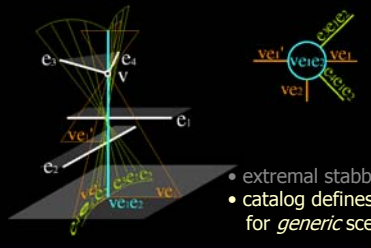
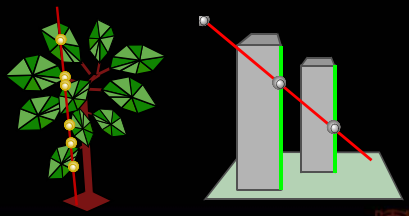


- extremal stabbing line ve_1e_2
- catalog defines adjacencies for *generic* scenes

Need to Treat Degeneracies

- Real scenes are degenerate !
- Catalog will fail



Our Solution

- Generalize the idea of extremal stabbing line (ESL)
- Develop a robust ESL casting process
- Robust swath construction
- Robust blocker predicates

Previous Work

- Analytic visibility
  - aspect graph [Koenderink '79]
- Analytic visibility in graphics
  - extremal stabbing lines, and swaths [Teller '92]

Previous Work

- Discontinuity Meshes
  - [Heckbert '91, '92], [Lischinski et al. '92]
  - complete DM [Drettakis & Fiume '94], [Stewart & Ghali '94]
- Visibility Complex and Visibility Skeleton
  - [Durand et al. '96, '97]

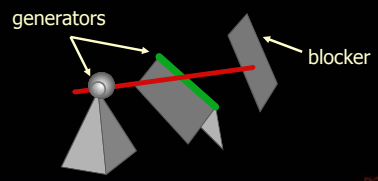
Previous Work

- Epsilon geometry
  - imprecise calculations [Salesin et al. '89]
- Interval methods
  - implicit functions etc. [Snyder '92]
  - ray tracing [Bala et al. '99]

Overview

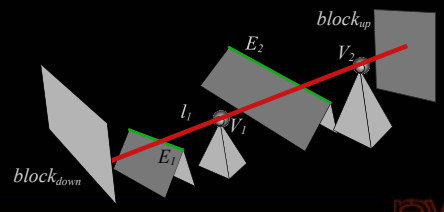
Generalized Visibility Events

- Basic definitions
  - generator: edge or vertex of the scene
  - blocker: any geometric element



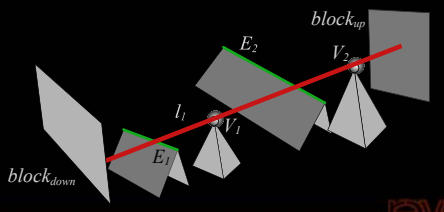
Generalized Visibility Events

- Extremal Stabbing Line (*ESL*):
  - quadri-tangent (VV, VEE, E4)
  - data structure containing generators



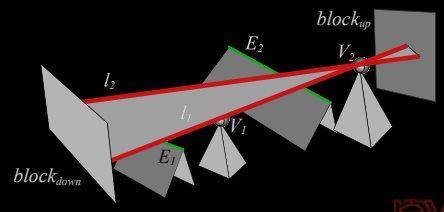
Generalized Visibility Events

- General Extremal Stabbing Line
  - catalog will fail



Generalized Visibility Events

- Critical Line Swath
  - connects extremal stabbing lines
  - defined procedurally



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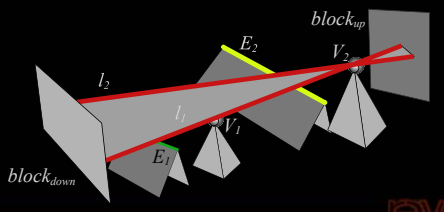
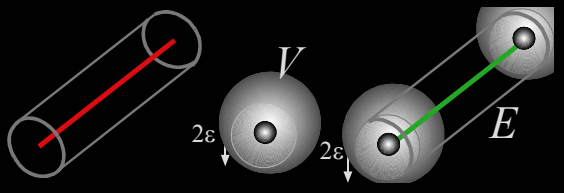


Overview

Enumeration and Validation

- On demand computation for an emitter/receiver pair
  - equivalent to lazy evaluation of Visibility Skeleton
- Methodology to enumerate & validate ESL's and swaths
  - propose ESL's (VV, VEE, E4)
  - occlusion computations: ESL casting
    - treatment of degeneracies
  - join ESL's with swaths

Fat Elements



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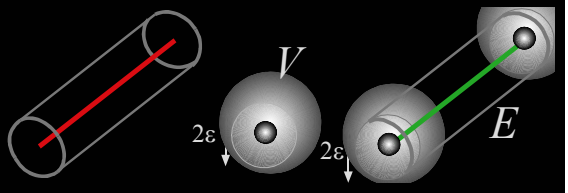
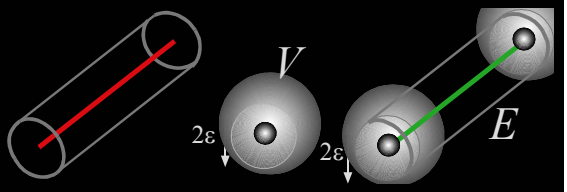


fat line

Fat Elements

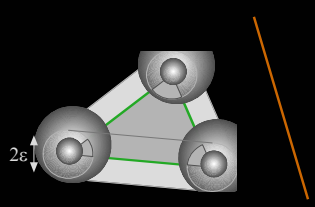


fat line fat elements

ESL Casting Algorithm

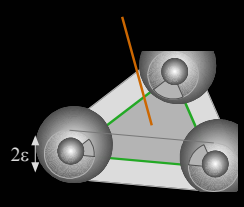
- ε methods or predicates for ESL-face interactions
- local occlusion test
- casting process

ESL-face Interaction



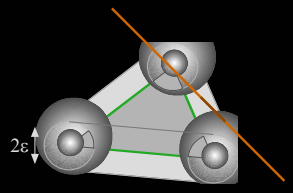
no stab

ESL-face Interaction



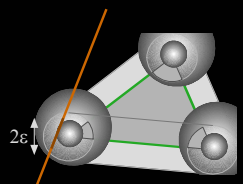
full stab

ESL-face Interaction



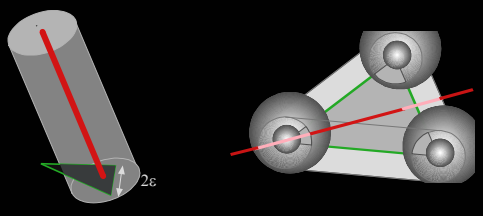
edge stab

ESL-face Interaction



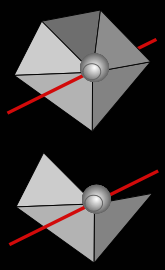
vertex stab

ESL-face Interaction



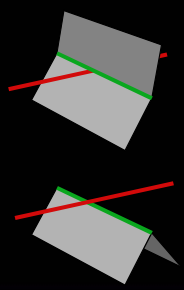
multi stab

Local Occlusion Test



- blocker
- generator

Local Occlusion Test

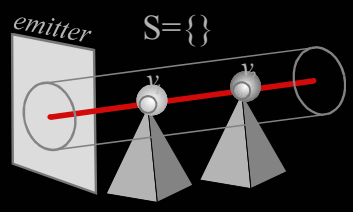


- blocker
- generator

ESL Casting

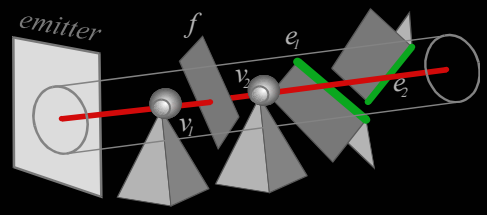
- ESL candidate with *native* generators
  - VV, VEE, E4
- S initially an empty set
- Algorithm: cast a line in scene
  - for each hit element, blocker/generator ?
    - if generator, insert to S
    - else stop
- ESL valid if all native generators in S

ESL Casting

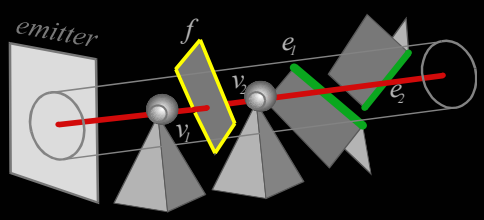


Native VV ESL

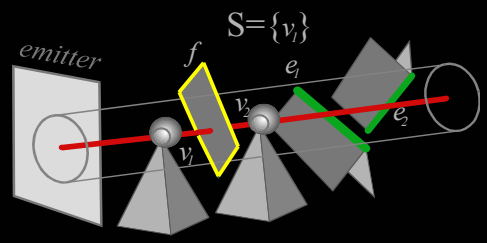
ESL Casting



ESL Casting

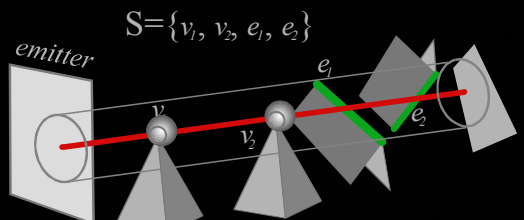


ESL Casting



Native generators not included in S: invalid ESL

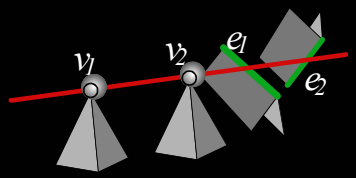
ESL Casting



Native generators included in S: valid ESL

Redundant ESL's

- Redundant enumerations



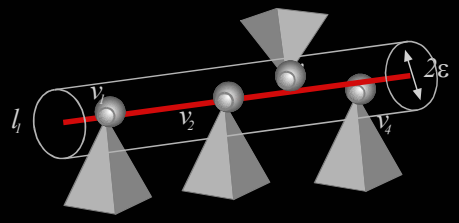
- v_1, v_2
- v_1, e_1, e_2
- v_2, e_1, e_2

Redundant ESL's

- Two conditions for redudancy:
  - combinatorial condition: are the native generators contained in S ?
  - topological condition: is the distance smaller than epsilon ?
    - distance: within the shaft

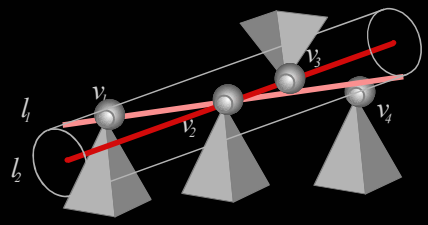
note: test performed **before** casting

Redundant ESL's



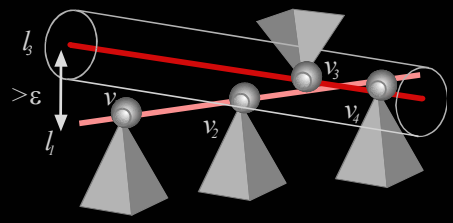
ESL with $S = \{v_1, v_2, v_3, v_4\}$ where v_1, v_2 native

Redundant ESL's



Both criteria are met: l_2 is redundant

Redundant ESL's



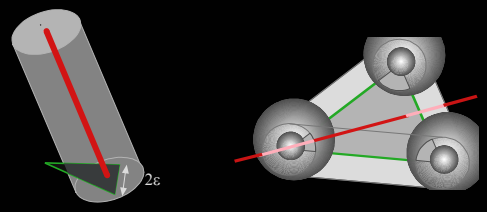
Combinatorial condition met, but not topological: l_3 is maintained

Critical Line Swaths

- Enumeration:
  - loop through VE and EEE
  - shared pair of ESL's ?
  - if yes, create candidate swath
- Validation:
  - assumption: all ESL's computed
  - occlusion test
  - midline casting

Overview

ESL-face Interaction

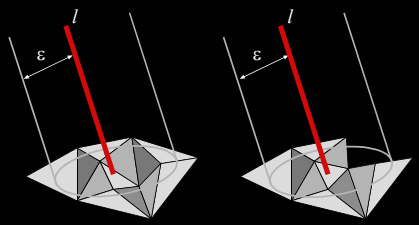


multi stab

Robust Blocker Predicates

- Multi-face
  - connectivity available
- Blocker-fan
  - connectivity unavailable or touching objects

Multi-face Construction



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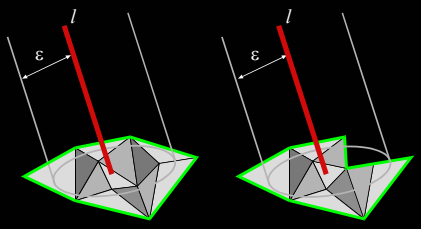
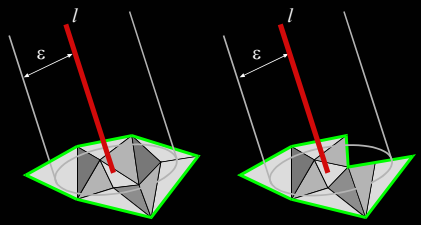


blocked

Multi-face Construction



blocked not blocked

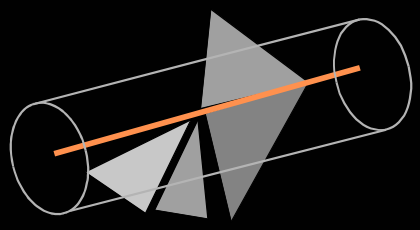
Blocker-fan

- Progressive contribution to ray occlusion
  - contacts
  - special-hit configurations
  - identification of the blocker (vertex/edge/face)

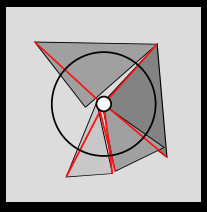
Blocker-fan

- Based on thick slices: depth component added to regular slices
  - progressively insert thick slices
  - merge slices only if depth overlaps
  - if complete disc, last element is blocker

Blocker-fan

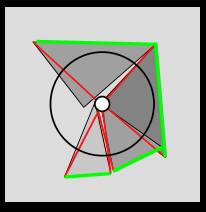


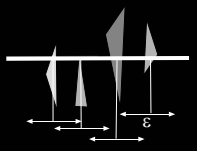
Blocker-fan



slices do not form a complete disc

Blocker-fan

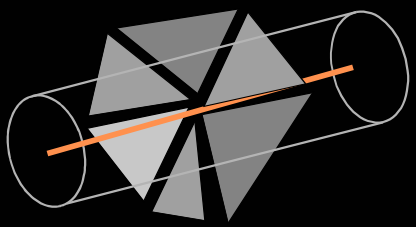




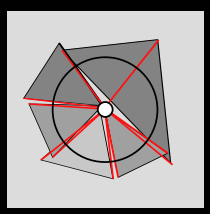
slices do not form a complete disc

slices do not overlap in depth: not blocked

Blocker-fan

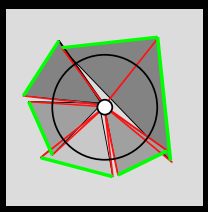


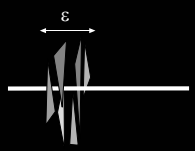
Blocker-fan



slices form a complete disc

Blocker-fan





slices form a complete disc

slices overlap in depth: blocked

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Implementation and Results

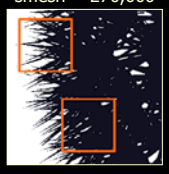
- Shadow boundary computation
  - Point or Directional Light source
    - equivalent to a 2D problem
    - constrained Delaunay triangulation for lighting
  - Area (polygonal) light source
    - shadow boundaries (discontinuity mesh)
    - problem with CDT

64,000 input polygons

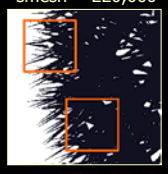
eps = 0.0001

eps = 0.001

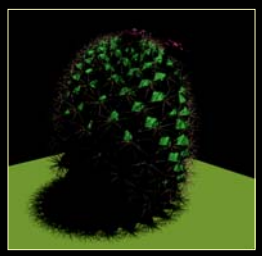
smesh = 270,000



smesh = 220,000



Cactus Model

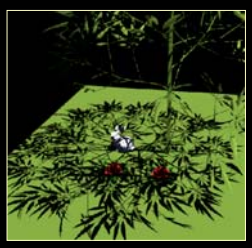


34,000 input polygons

428,000 shadow mesh

1 h 10 min (Pentium III, 1 Ghz)

Big Scene



121,000 input polygons

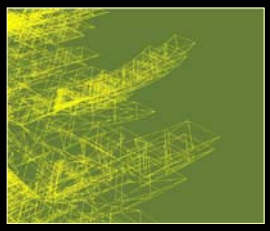
330,000 shadow mesh

10 min (Pentium III, 1 Ghz)

Big Scene vs Cactus

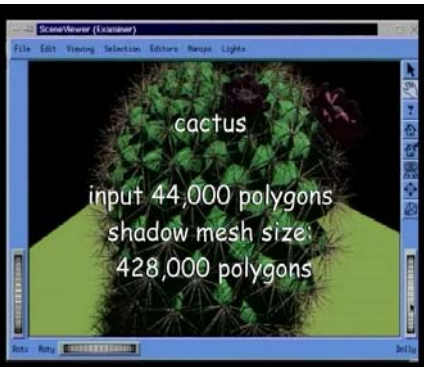
- Big Scene
  - input: 121,000
  - smesh: 330,000
  - time: 10 min
- Cactus
  - input: 34,000
  - smesh: 428,000
  - time: 1 h 10 min

Soft Shadow Boundaries



34,000 input polygons 464,000 swaths

17 h 30 min (Pentium III, 1 Ghz) naïve algorithm



Discussion

+ robust analytic visibility for real scenes
+ consistent feature merging

- computationally expensive
- size of soft shadow mesh

Future Work

- lighting for soft shadows
  - simplification of shadow mesh
  - robust CDT
- optimization for soft shadows
  - hierarchies
- general visibility tool
  - global illumination
  - walkthroughs etc.

Conclusion

- generalized definition of visibility events
- epsilon visibility methods
- robust ESL casting and swath construction algorithm
- robust blocker predicates
- results on real-world models

Acknowledgments

- Frédo Durand for initial ideas and help
- Marc Stamminger and Pierre Poulin
- Ecole Nationale Supérieure des Télécommunications (Paris)
- INRIA National Research Initiative (ARC) "Visi3D" on 3D Visibility

Thank you

http://www-sop.inria.fr/reves

Thank you

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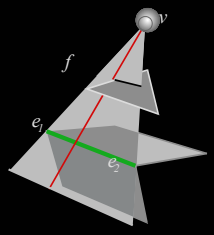
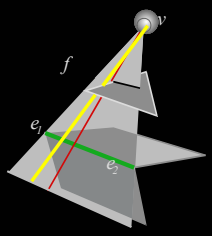
Swath validation



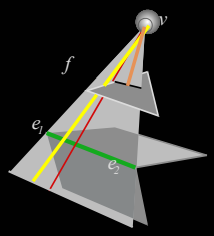
Swath validation

- midline not blocked: valid swath



Swath validation

- midline blocked: no swath



Sharp shadows

- Generators
  - Light source (vertex or equivalent)
  - For ESL candidates:
    - two edges (one silhouette), SEE
    - vertex (connected to a silhouette edge), SV
  - For Swaths
    - edge (silhouette), SE
- Enumeration
  - vertices and edges pairs, with nested ESL casting
  - Swath, with nested Swath validation

Soft Shadows

- Light source is a convex planar polygon
- Generators
  - Vertex (Vs) or Edge (Es) of the light source
  - ESL candidates
    - VsV, VsEE
    - EsVE, EsEEE
  - Swath candidates
    - VsE
    - EsV
    - EsEE

Generalized Visibility Events

- On demand computations for an emitter/receiver pair
  - equivalent to lazy evaluation of Visibility Skeleton

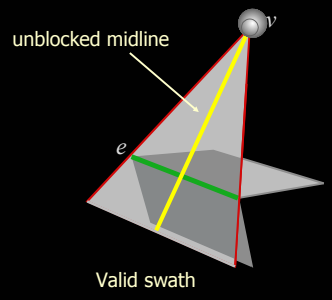
Discussion

- Possible cases of failure
  - faut la faire

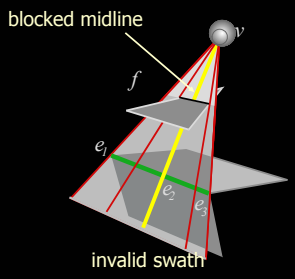
Enumeration and Validation

- ESL Casting
  - from an ESL candidate (set of generators, marked as native), test occlusion
- Swath Validation
  - from a swath candidate (set of generators, native), test critical line set and occlusion

Swath validation

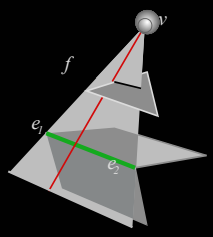


Swath validation



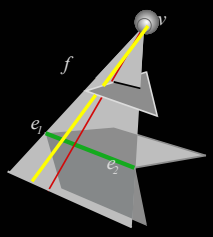
Thank you

Swath validation



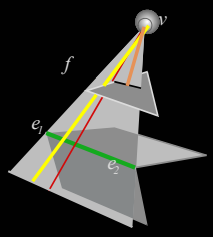
Swath validation

- midline not blocked: valid swath

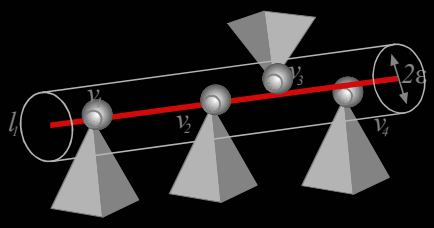


Swath validation

- midline blocked: no swath

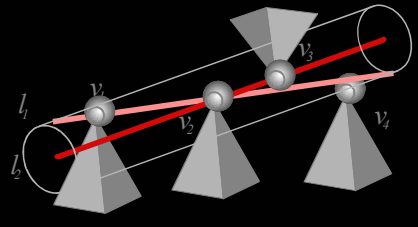


Redundant ESL's



ESL with $S = \{v_1, v_2, v_3, v_4\}$ where v_1, v_2 native

Redundant ESL's



Both criteria are met: l_2 is redundant